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Phase-contrast Imaging of Fatigue Crack Propagation through Grain Boundaries

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Single-crystal nickel-base superalloys are used in critical aeronautic and power-generation applications where they undergo very high-cycle fatigue. They can have complicated dendritic microstructures and grain boundaries. The microstructure can drastically influence fatigue-crack growth, a dominant failure mode, affecting the growth rate and morphology. Synchrotron x-ray radiography is ideal for imaging crack growth *in situ* and in real time, and the spatial coherence allows phase-contrast imaging of the interfacial topology of minimally opened cracks. We installed a custom-built ultrasonic-fatigue instrument at sector 32-ID for stable fatigue-crack growth in thin, dog-bone-shaped specimens. Samples were held with a mean tensile stress and cycled in tension at 20 kHz at $R = -0.1$. When crossing low-angle grain boundaries at large stress-intensity factors ($K > \sim 7 \text{ MPa}\cdot\text{m}^{1/2}$), cracks remained on $\{111\}$ planes without changing their growth rate appreciably. At lower K near the crack-initiation threshold, cracks followed grain boundaries by shifting among planes in the $\{111\}$ family. At large-angle grain boundaries, cracks were arrested, requiring larger K to propagate further. After traversing the boundary, they would frequently continue to propagate intergranularly or non-crystallographically. These results are directly relevant to the behavior of superalloys under actual operating conditions.